EUVL Image-based Aberration Metrology

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**GLOBALFOUNDRIES*

EUVL challenges

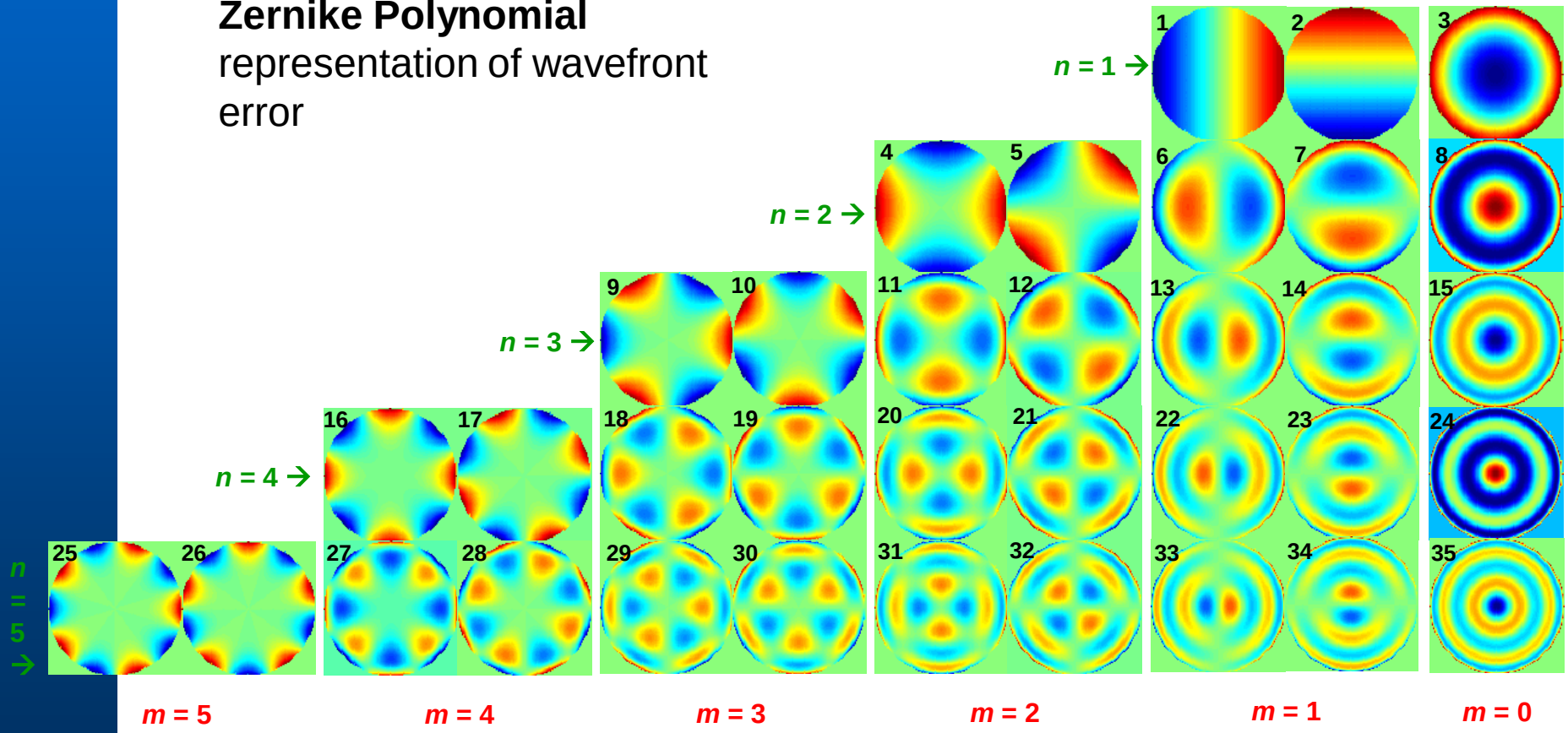
- **Source Power**
- **Resist**
- **Optics**
- **Illumination**
- **Reticle Defectivity & inspection/ repair**
- **Shadowing**
- **Flare**
  - Scales with λ , EUVL needs ~14x lower roughness lens than ArF
- **Aberrations**
  - EUVL aberrations levels need to be controlled to λ/20 or better, while ArF needs λ/100
  - Additional concerns, which are manageable in ArF, but maybe a concern in EUVL include: thermal drift, monitoring, tool matching, & lens degradation
  - Measurement & monitoring will likely be more critical than other lithography generations
  - Image based aberration metrology has a window of opportunity with EUVL

Benefits of estimating lens aberrations from lithographic images

- Has been used previously in DUV applications
- Uses well characterized **photoresist process**
- Targets are **readily available** on current IC reticles
- Ability to monitor aberration levels **during system use**
- Can be **easily accomplished** with a small amount of metrology and exposure time
- Not a replacement for onboard metrology, but a complementary method

Wavefront aberration

Zernike Polynomial representation of wavefront error



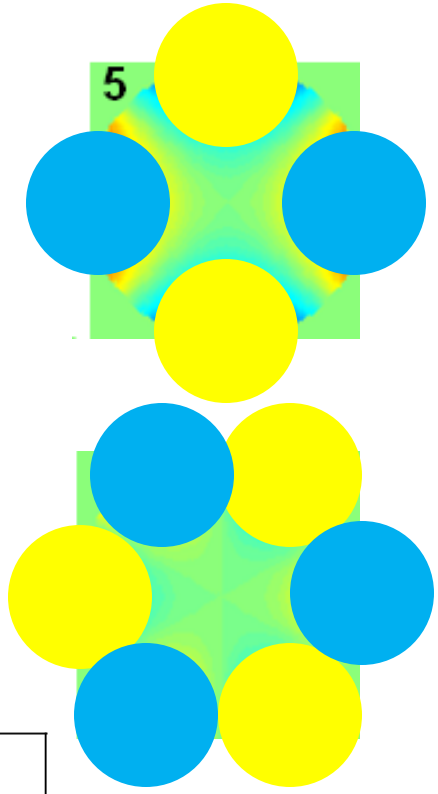
EUVL System under study

- ADT
  - Partial coherence 0.5, 0.25 NA, 4X, full field
- MET
  - Programmable illumination, 0.3 NA, 5X, 1x3mm field
- NXE3300
  - Variable partial coherence, 0.32 NA, 4X, full field
- Other EUVL systems

Aberration test target selection

ADT, 0.25 NA, σ=0.5

- Criteria
  - Easily available on current EUVL reticles
  - Diffraction orders interact with aberration of interest in the pupil plane
  - High resist CD change for a given aberration level
  - Partial coherence of 0.5 causes higher order aberrations to be averaged with lower order aberrations in all targets



Binary Mask Structure	{CD ver} – {CD hor}	{CD left} – {CD right}	{CD left} – {CD right}	CD Through Pitch
Aberration Sensitivity	Astigmatism	Coma/Trifoil	Trifoil/Coma	Spherical

Aberration retrieval method

- Aberration retrieval using target images collected through focus and/or exposure dose in a partially coherent optical system
- Inverse imaging problem (numerical solution)
  - Use simulation/modeling for forward calculations to predict image shape in the image plane
  - Solve for match between reconstructed and measured image shape using numerical methods while varying Zernike coefficients
  - Iterative search algorithm to find aberration signature consistent with images through-focus/dose

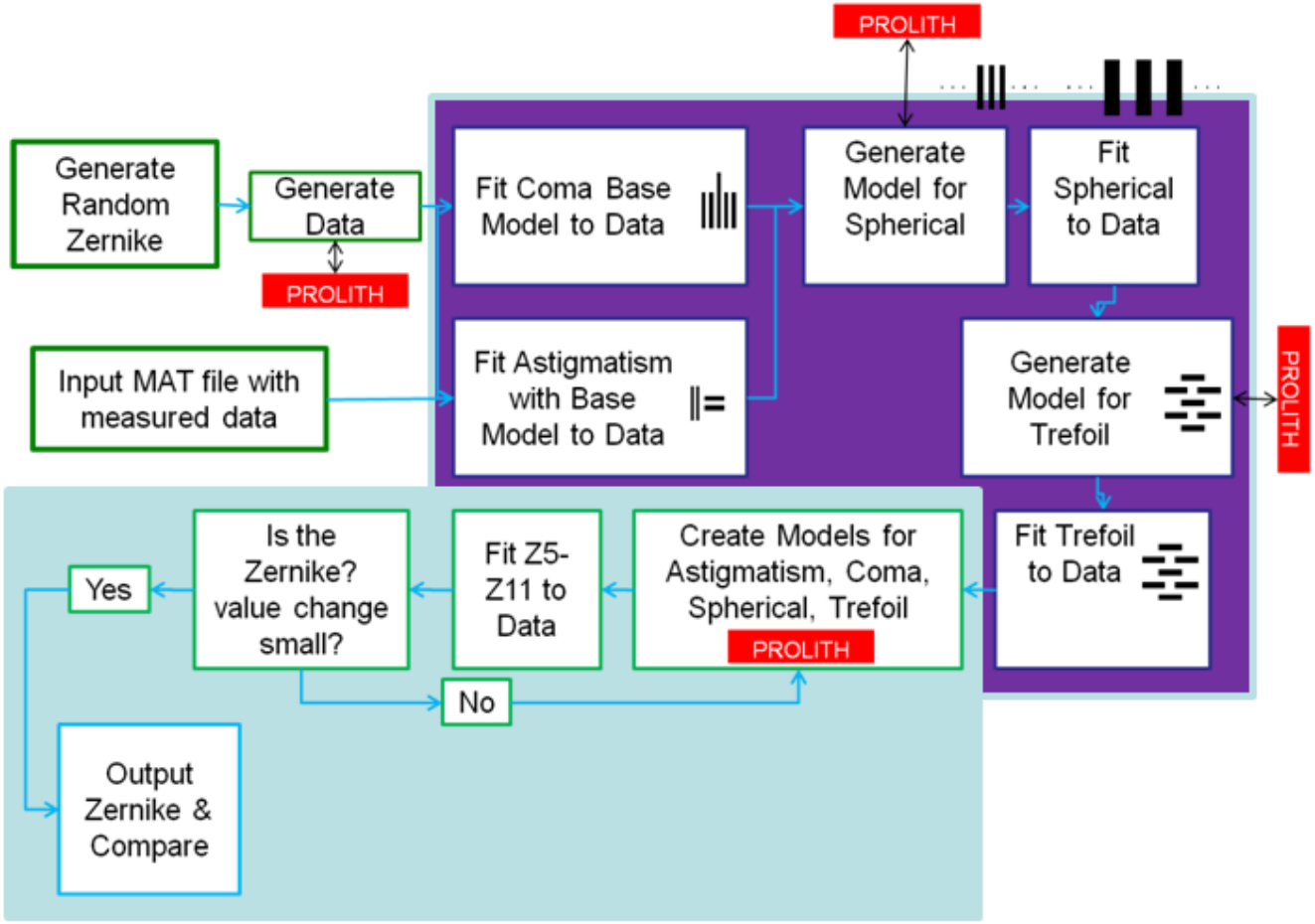
Extraction Flow

Stage 1

initial extraction

Stage 2

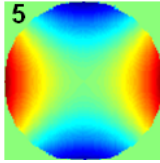
Iteration creating linear models using the previous iteration's outputs

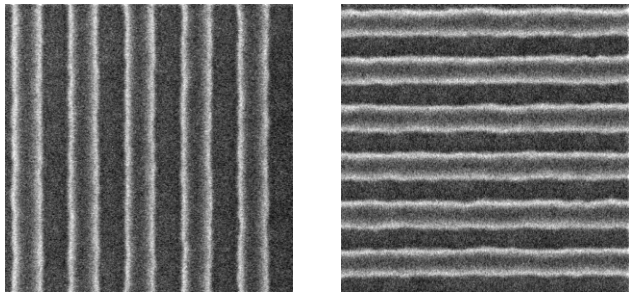


Aberration Measurement
First test case

- ASML AD1 (CNSE) λ=13.5nm, NA=0.25, σ=0.5
- Exposure and SEM data collected over the period of a month
- Film stack: Bare Si + ODL102 100 nm + SIARC SHB A940 35 nm +75 nm SEVR139 on four wafers
- Structures ***(repeated three times per field)***
  - Astigmatism x (z5): P88 1:1 lines (reticle 1)
  - Astigmatism y (z6): P90 (45 degree) 1:1 lines (reticle 2)
  - Coma x (z7): P70 5-bar 1:1 (reticle 1)
  - Coma y (z8): rotated P70 5-bar 1:1 (reticle 1)
  - Spherical (z9): P75 – P400 35nm CD trench (reticle 1)
  - Trefoil x (z10): 30nm T-brick wall bright field (reticle 1)
  - Trefoil y (z11): not available

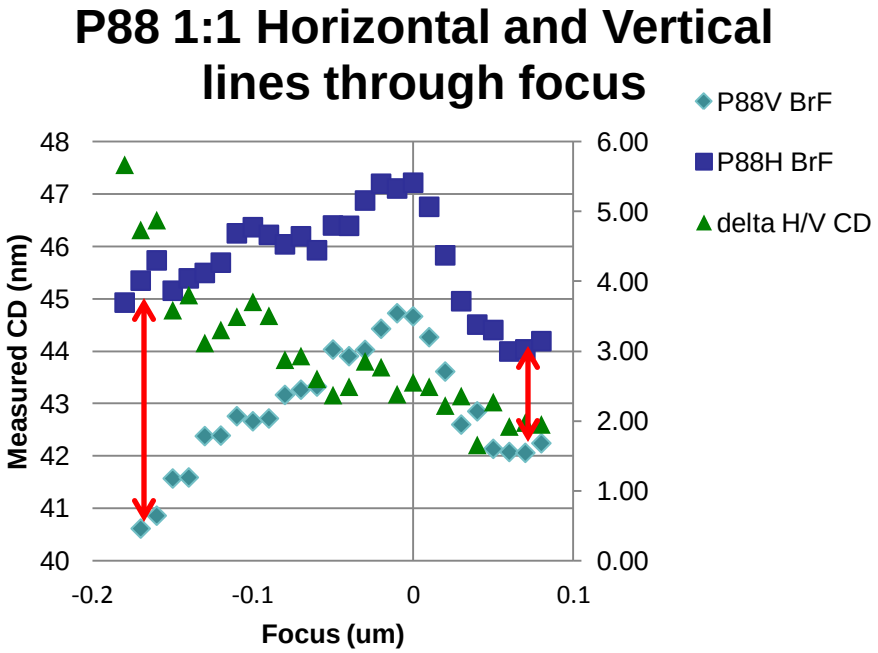
Measured H-V CD Through Focus



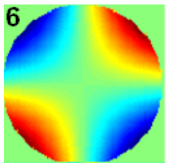


P88 1:1 Horizontal and Vertical

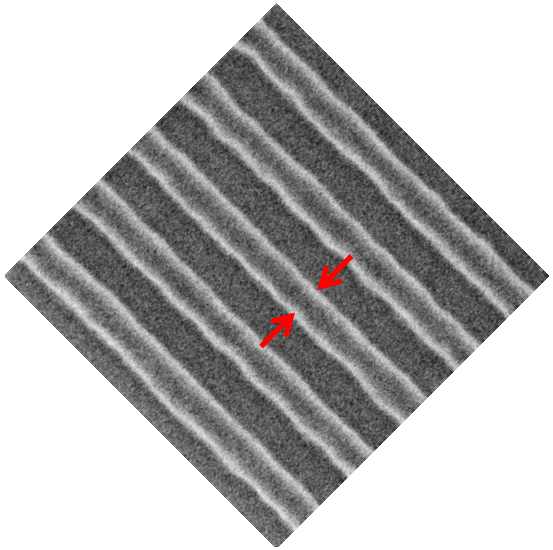
Dose: 21 mJ/cm^2
Focus start: -0.18um
Focus step: 0.01um

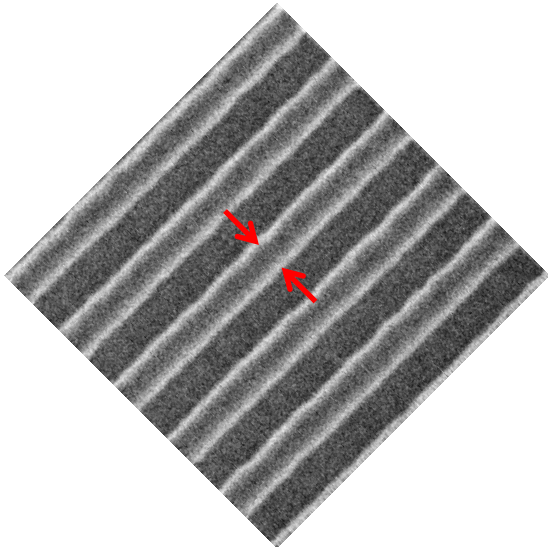


The change in the difference in CD between horizontal and vertical lines through focus can be correlated to the amount of x astigmatism in the system.

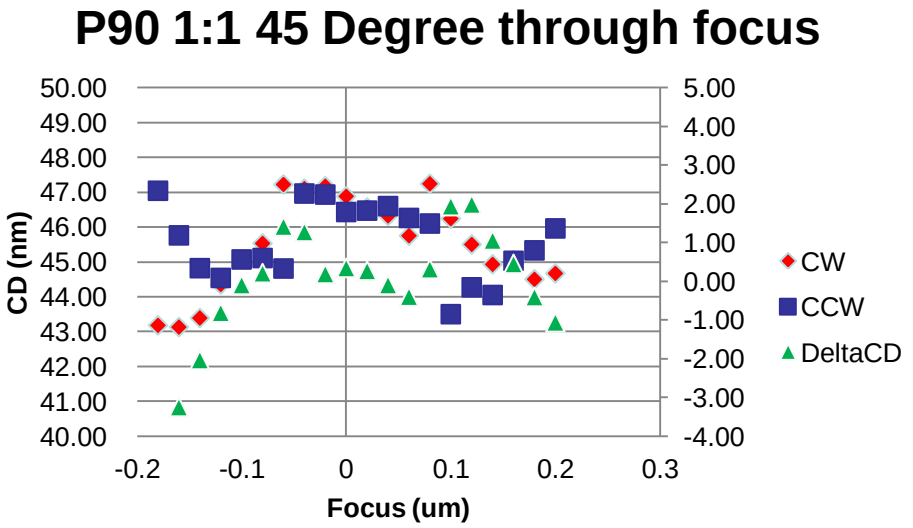


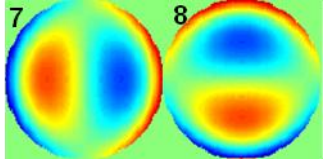
P90 1:1 45 degree lines



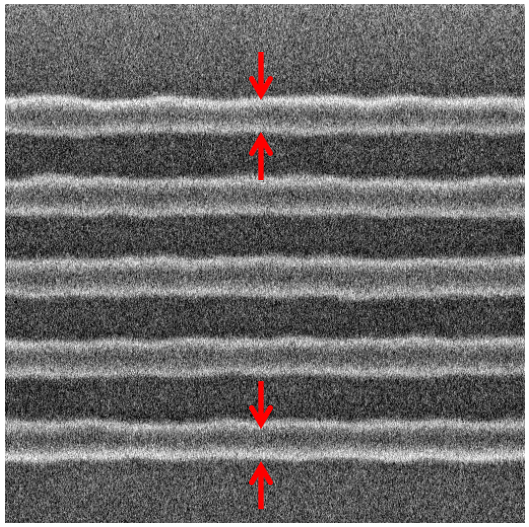


- Dose: 21.5 mJ/cm^2
- Focus start: -0.21um
- Focus step: 0.02um

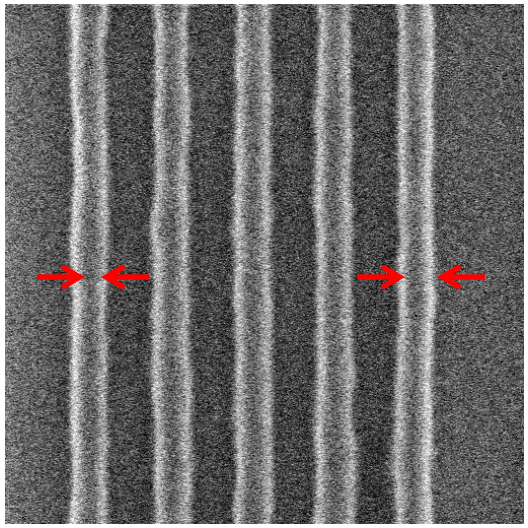




Coma X & Y



P70 1:1 5 Bar H (coma y)

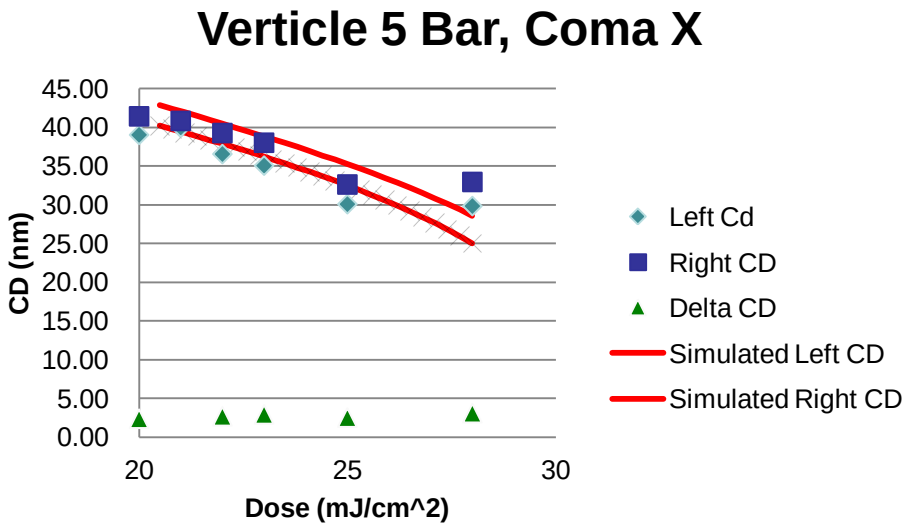


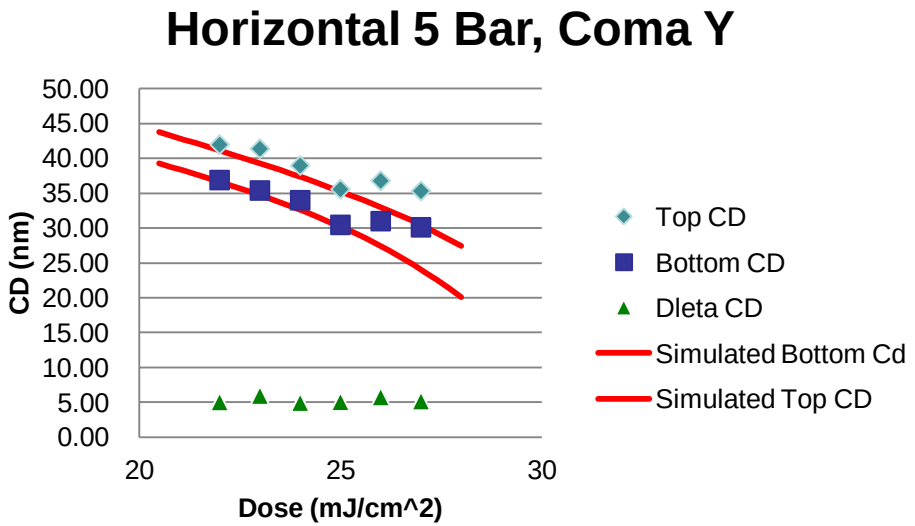
P70 1:1 5 Bar V (coma x)

Dose Start: 22 mJ/cm^2
Dose Step: 1 mJ.cm^2
Focus start: -0.05um

- Left and right (top and bottom) CDs of a 5 bar structure were measured

Measured 5 Bar Data





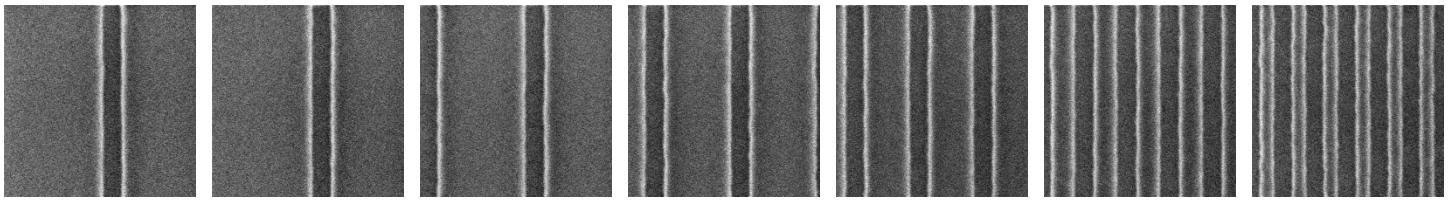
Left/Right Delta CD ~ 2.5nm

Top/Bottom Delta CD ~ 5nm

The difference in CD of the left and right lines of the 5 bar structure matches well with the model, the CD is dependent on dose matching between the model and scanner.

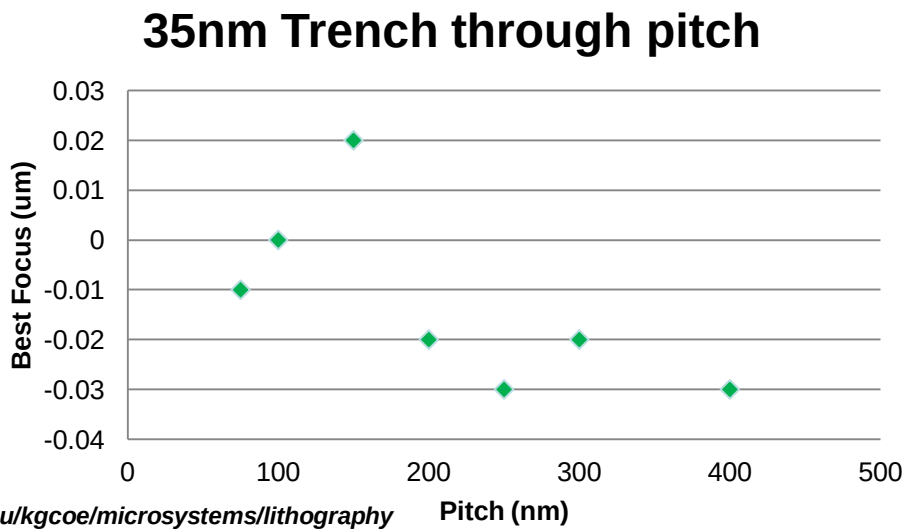
*The extraction only uses the CD difference between left and right bars. This makes the metric somewhat CD independent.

Best focus through pitch



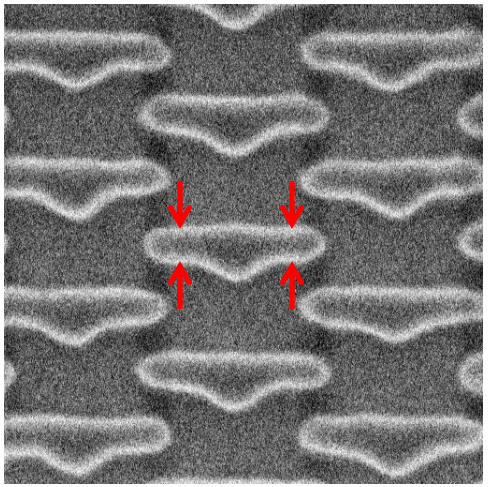
- 35nm trench through focus
- Center dose: 27 mJ/cm^2
- Dose step: 1mJ/cm^2
- Focus Center: -0.05um
- Focus Step: 0.03 um

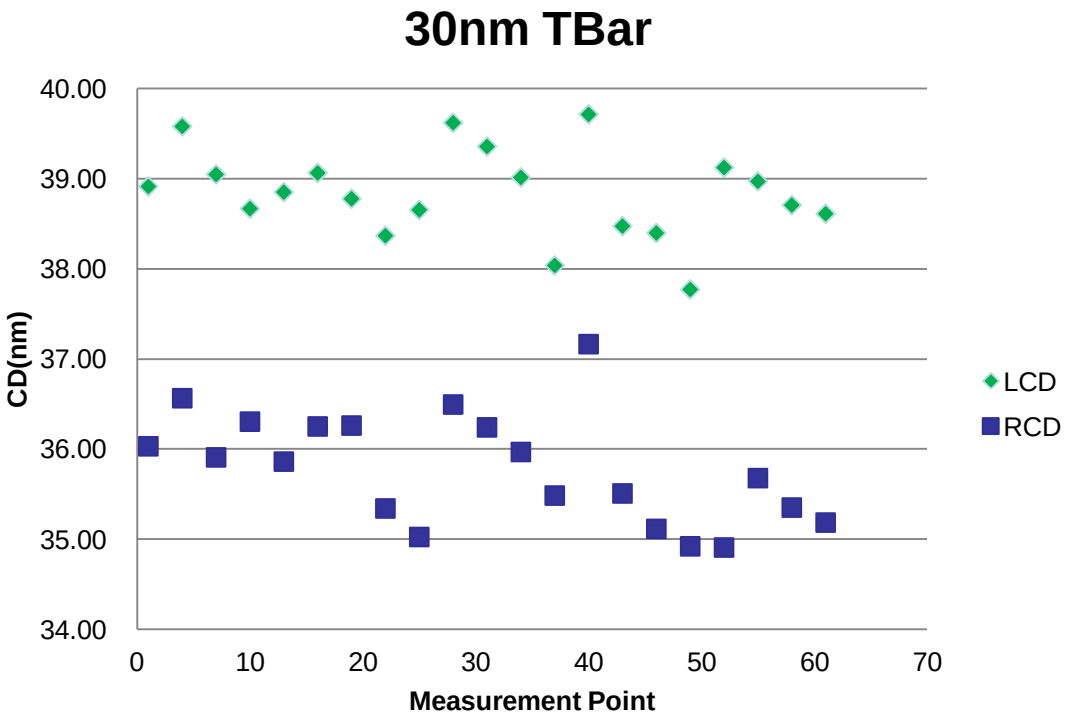
Pitch (nm)	BF (um)
400	-0.03
300	-0.02
250	-0.03
200	-0.02
150	0.02
100	0
75	-0.01



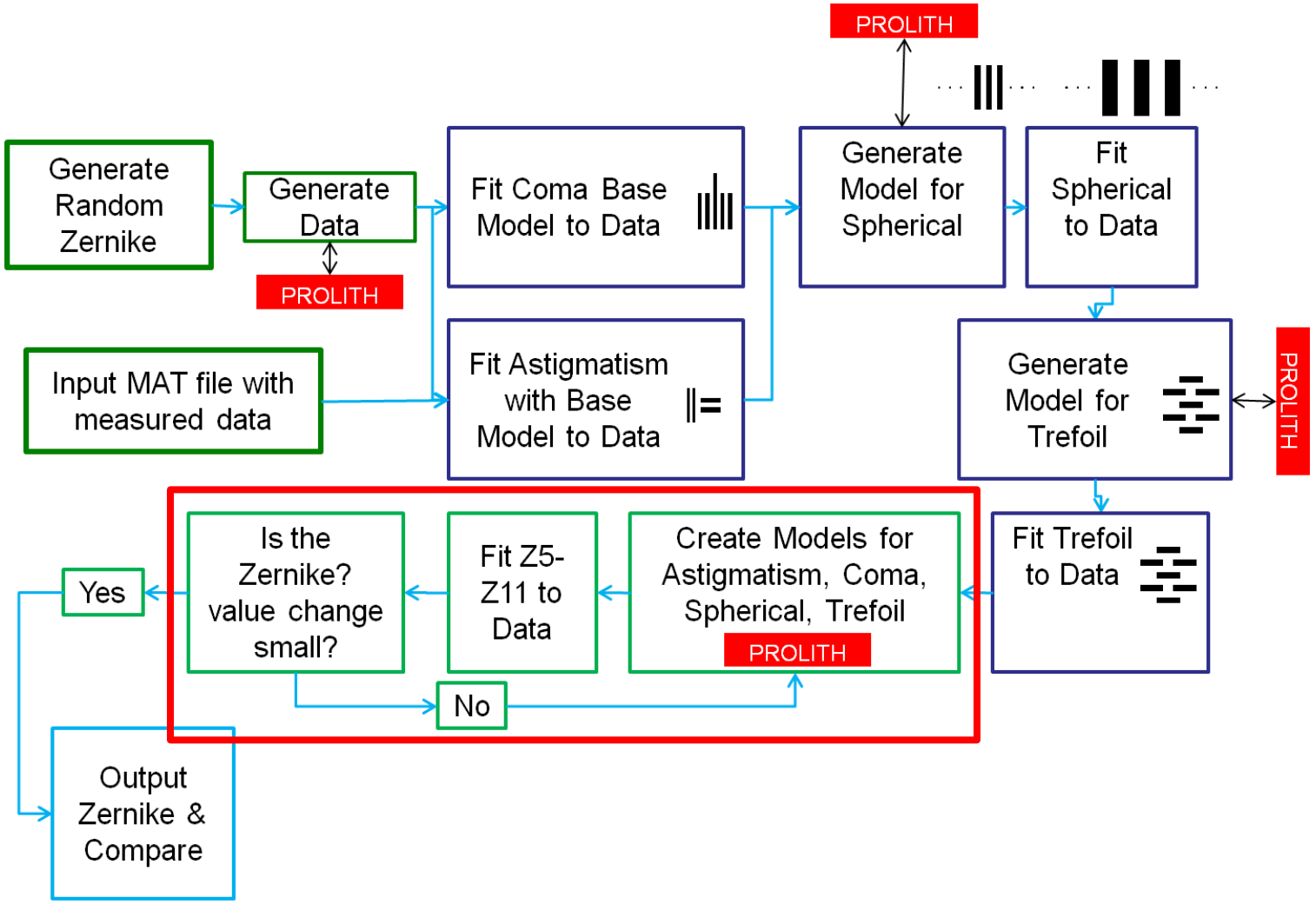
T – Bar Structure

- 30nm T-Bar
  - Dose: 22mJ
  - Focus: -0.05um
  - Production



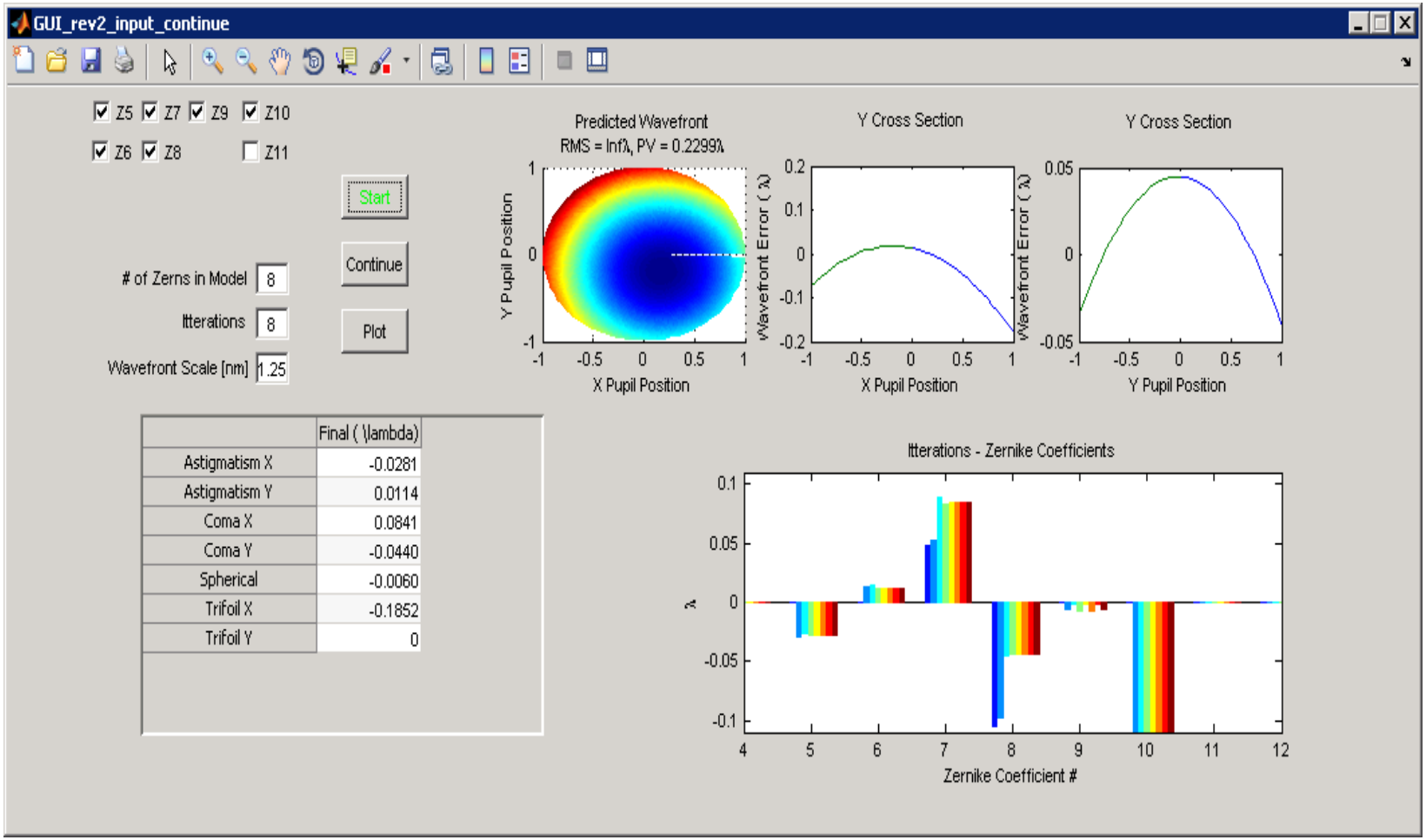


Extraction Flow



Stage 2 Details

Extraction and user interface



	Final (\lambda)
Astigmatism X	-0.0281
Astigmatism Y	0.0114
Coma X	0.0841
Coma Y	-0.0440
Spherical	-0.0060
Trifoil X	-0.1852
Trifoil Y	0

Stage 2 Details
Output

- Eight iterations took ~4 hours on 8 cores
- Zernike coefficients were extracted
  - Astigmatism X (-0.028 waves)
  - Astigmatism Y (0.014 waves)
  - Coma X (0.085 waves)
  - Coma Y (-0.044 waves)
  - Spherical (-0.006 waves)
  - Trefoil X (-0.185 waves)
- No Results for Trefoil Y

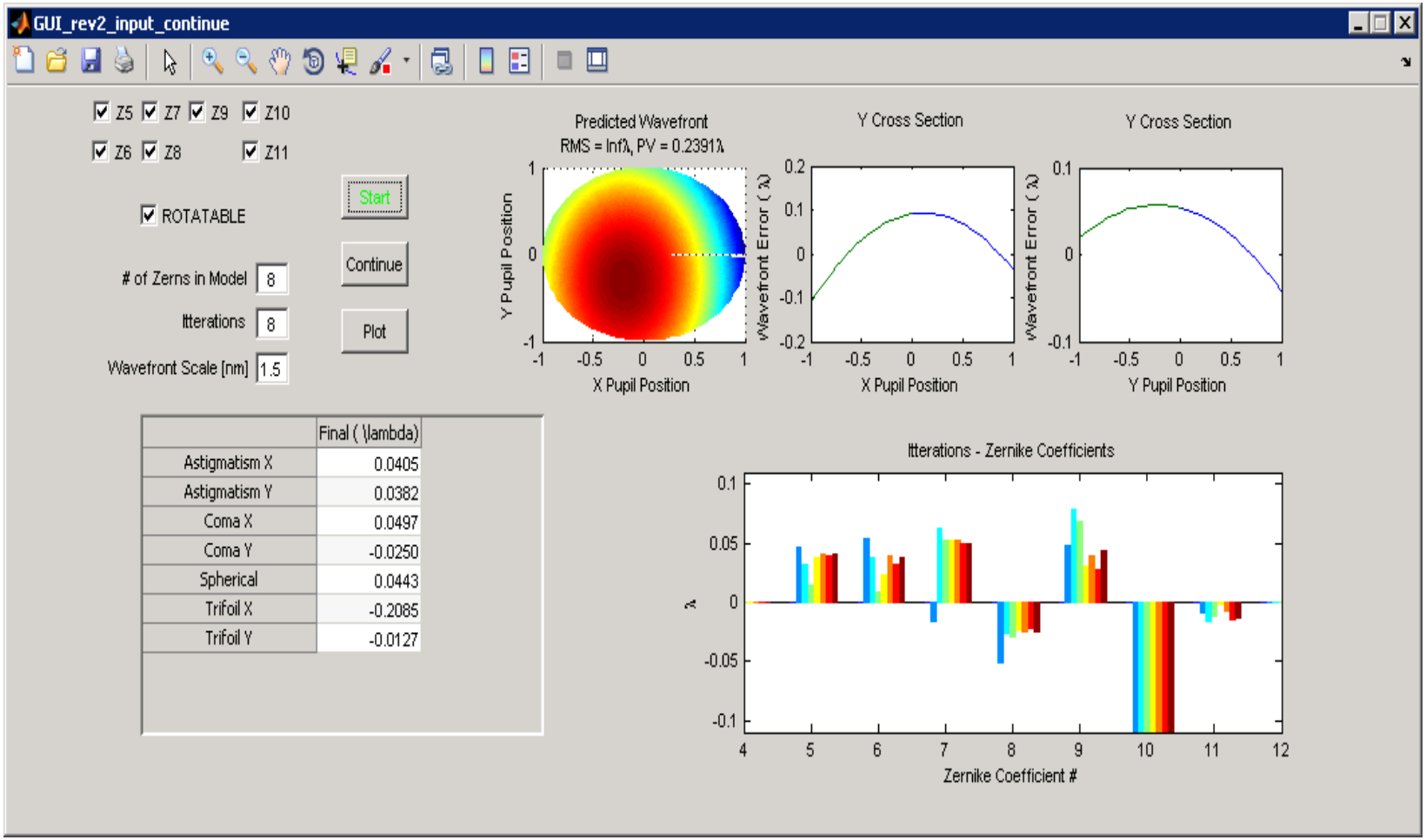
Aberration Measurement

Second test case

- ASML AD1 (CNSE) λ=13.5nm, NA=0.25, σ=0.5
- Exposure and SEM data collected over the period of a few days
- Film stack: Bare Si + ODL102 100 nm + SIARC SHB A940 35 nm +75 nm SEVR139 on three wafers
- Structures ***(repeated three times per field)***
  - Astigmatism x (z5): P80 1:1 lines (reticle 3)
  - Astigmatism y (z6): P80 (45 degree)1:1 lines (reticle 3)
  - Coma x (z7): P70 5-bar 1:1 (reticle 3)
  - Coma y (z8): rotated P70 5-bar 1:1 (reticle 3)
  - Spherical (z9): P64 – P192 32nm CD line (reticle 3)
  - Trefoil x (z10): 30nm T-brick wall bright field (reticle 3)
  - Trefoil y (z11): rotated 30nm T-brick wall bright field (reticle 3)

Stage 2 Details

Extraction and user interface



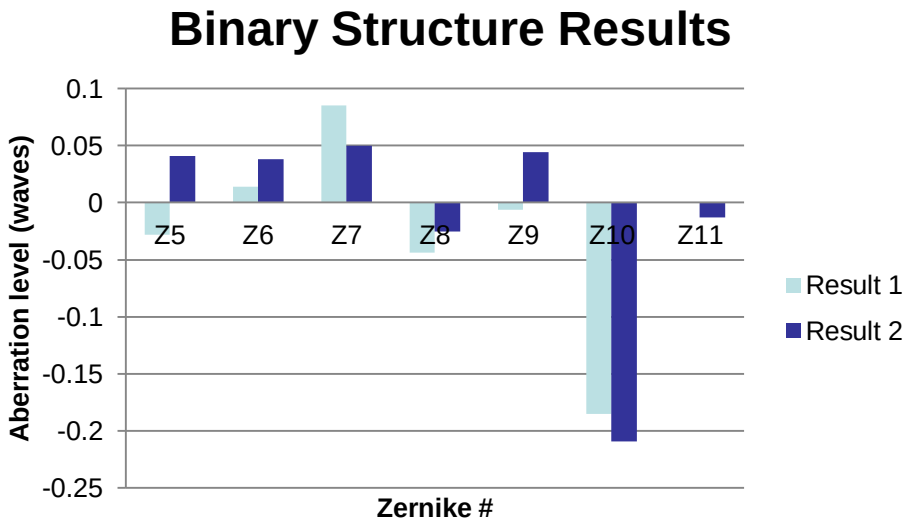
	Final (\lambda)
Astigmatism X	0.0405
Astigmatism Y	0.0382
Coma X	0.0497
Coma Y	-0.0250
Spherical	0.0443
Trifoil X	-0.2085
Trifoil Y	-0.0127

Stage 2 Details
Output

- Eight iterations took ~4 hours on 8 cores
- Zernike coefficients were extracted
  - Astigmatism X (0.041 waves)
  - Astigmatism X (0.038 waves)
  - Coma X (0.050 waves)
  - Coma Y (-0.025 waves)
  - Spherical (0.044 waves)
  - Trefoil X (-0.209 waves)
  - Trefoil Y (-0.013 waves)

Comparing the two experiments

- Test target differences
  - Reticles
  - Target location on Reticle
  - Mask stack
  - Targets



- Trefoil x (Z_{10}) is dominate aberration
- Collection time may influence results
- Reticles may have signature
- Field position varied

Summary

- A method was developed to measure and extract aberration levels using image based testing
  - Uses standard mask targets and few wafers
  - Iterative inverse wavefront solution in a multivariable environment
  - Interactive user interface
- Current efforts include more repeatability and predictability studies
- Targets that include phase structure (PSM) can add additional sensitivity and higher-order terms- experiments underway

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